VI

THE CLOUDS OF MAGELLAN

THE two large isolated nebulous patches of light in the southern sky, which have attracted the attention of southern travellers from the time of Magellan onward, are a source of much useful information in the measurement and understanding of all stellar systems. Studied from the southern stations of the Harvard and Lick observatories, in Peru and Chile, they have proved a happy hunting ground in which to find gaseous nebulae, stars of the peculiar P Cygni type, Class O supergiant stars, star clusters of various sorts, and, perhaps most important of all, a wealth of variable stars of the Cepheid type. The Small Cloud is the system for which Hertzsprung first estimated a distance by means of Cepheid variables, following Miss Leavitt's pioneer work on the relation between the brightness and periods of the variable stars. In more recent studies at the Harvard Observatory we have established the period-luminosity relation in the Small Cloud in the form that is currently used for the estimation of the distances of Cepheid variables.

In both past and current investigations of the Clouds of Magellan we have taken full advantage of our position as external observers; future studies will still further exploit the advantages of this objectivity. The Clouds are the nearest of isolated external galaxies and the forthcoming analyses of the spectra, light variations, distribution, and motions of their stars, clusters, and nebulae will reflect on

the problems of our local system and of the star clouds in the Milky Way. The investigations of the Magellanic Clouds that are now in progress at the Harvard Observatory will be briefly described in the following pages, the progress report being prefaced by a brief description of the Clouds in order to orient the reader with regard to these nearest representatives of the spiral nebula family.

The Large and Small Magellanic Clouds are in the southern constellations of Dorado and Tucana, respectively, with angular diameters of approximately 7 and 3.5 degrees. Both are found to be at a distance of about ninety thousand light years, if we use for deriving this value the reference system now generally though provisionally adopted.[1]

The speed of recession is +275 kilometers per second for the Large Cloud and +170 kilometers per second for the Small, and Hertzsprung has shown reason for believing that the two Clouds move along parallel paths. I think it likely that the major part of the observed recessional speeds is but a reflection of the motion of the local system with respect to the main mass of the Galaxy, including the globular star clusters and the Clouds of Magellan. Luyten has made a provisional study of the proper motions of stars in the field of the Large Magellanic Cloud.

On early photographs with the Bruce telescope Miss Leavitt discovered nearly eighteen hundred variable stars in the two Clouds, and up to the present the periods and light curves of two hundred have been determined. The positions and descriptions of many of the gaseous nebulae have

[1] All the distances mentioned in the last five sections of this article are based on the zero point of the period-luminosity relation which is given in Harvard Observatory Monograph No. 2. In the course of a few years a definitive revision will be possible, and then the distances here given can all be changed by a constant factor.

been published by Harvard investigators and preliminary measures made of the included globular star clusters.

The foregoing citation of observational results covers most of the knowledge of the Clouds up to the beginning of the current year. The following paragraphs report on investigations now in progress.

a. The Supergiant Stars. A survey some years ago of the Small Magellanic Cloud showed that it contains more than one hundred thousand stars brighter than absolute magnitude zero, with its most luminous members of magnitude −6. A recent survey of the distribution of magnitudes of stars in the Large Magellanic Cloud has led to the following estimates of its total population of highly luminous stars:

ABSOLUTE PHOTOGRAPHIC MAGNITUDE	TOTAL NUMBER OF STARS
]−5.0	735
−5.0 to −4.5	943
−4.5 to −4.0	1,460
−4.0 to −3.5	2,401
−3.5 to −3.0	3,262
−3.0 to −2.5	6,832
−2.5 to −2.0	11,077
−2.0 to −1.5	16,082
−1.5 to −1.0	23,172
−1.0 to −0.5	45,073
−0.5 to 0.0	103,354
	214,391

Since the Large Cloud covers forty square degrees, we must expect the adventitious appearance on the photographs of a large number of stars of our own system. The numbers just given have been corrected for these superposed

stars, using statistical tables derived by van Rhijn. Stars brighter than photographic absolute magnitude −2 are commonly referred to as supergiants, and the Cloud contains more than twenty thousand such objects. Stars brighter than absolute magnitude −5.0, which corresponds at the distance of the Large Cloud to apparent magnitude 12.1, are more than fifteen thousand times as bright as the Sun. Without further study of the spectra and motions we cannot distinguish these individual stars of enormous luminosity from the individual low luminosity superposed stars of our own system; all that we can say without such analysis is that in both of the Clouds there must be several hundred stars of this abnormally high real brightness; at the same time we should remember that similar stars are known in our local system where we can pick out a few individual supergiants, but cannot yet make a census.

b. Spectra of the Supergiants. The Henry Draper Catalogue of stellar spectra includes practically all stars brighter than magnitude 8.5 in the region of the Clouds of Magellan, and Miss Cannon has gone to much fainter magnitudes for objects of special spectral classes. As a part of the Henry Draper Extension, described in an earlier section, the classification of the stars in and around the Large Cloud, approximately to photographic magnitude 12.0, is now under way. When complete, this classification, even though provisional for a number of the fainter stars, will be of high importance for the study of stars of highest luminosity. Partial results are now available. The following tabulation refers almost wholly to stars between magnitudes 10 and 12. It gives in the second column the number of stars for each spectral class in or in front of the Large Cloud; the last column gives the corresponding numbers for a smaller control field adjacent to the Cloud. The distribution is

CLASS	CLOUD	FIELD
O	8	0
B	28	0
A	66	10
F	153	35
G	771	206
K	768	172
M	385	77
	2179	500

illustrated in Figures 18 and 19, where it is seen that the Class O and Class B stars are entirely absent from the field.

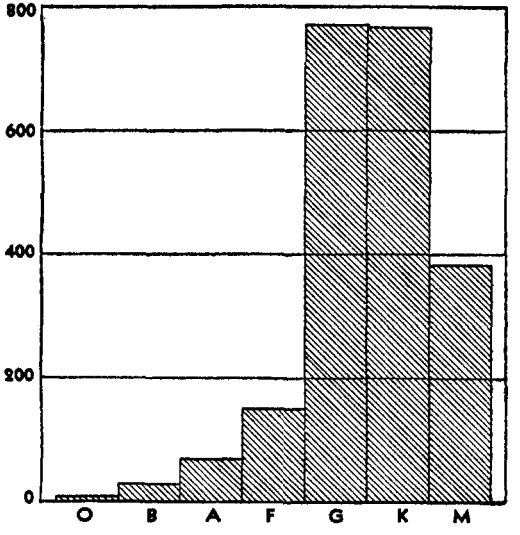

FIGURE 18. Distribution of spectra for the Large Magellanic Cloud.

But the diagrams in other respects are so nearly alike that we can fairly maintain that Figure 18 also refers almost wholly to non-Cloud stars. Perhaps, in addition to the stars of

Classes O and B, some of the Class K and Class M stars are members of the Cloud, but otherwise relatively few of the members are brighter than the twelfth magnitude unless their distribution among the spectral types is similar to that of dwarfs.

c. Open Clusters. The brightness of the individual stars

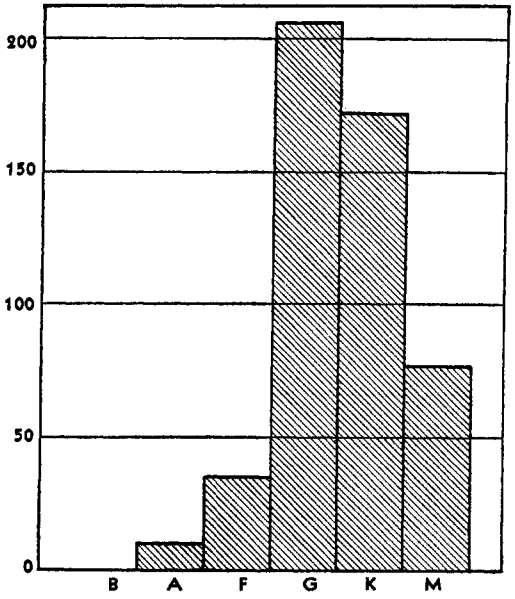

FIGURE 19. Distribution of five hundred spectra in a region on the southern border of the Large Magellanic Cloud.

in the different open clusters in the Large Cloud may have a direct bearing on our study of the open clusters in the galactic system. To estimate the distance of the galactic clusters we have in the first approximation assumed that the brightest stars are of about the same intrinsic luminosity in all clusters. Similar assumptions have been made by others who have worked on problems of galactic clusters. A current examination of the brightness of the clusters in the

Large Cloud shows, however, that the assumption is precarious. In Figure 20 the frequency of the brightest apparent magnitude for 153 open clusters is plotted. The magnitudes, estimated to the nearest half magnitude, are referred to the International Standards and apply in each cluster to the fifth brightest star. In order to avoid errors due to superposed objects, it is safer to take the fifth star in

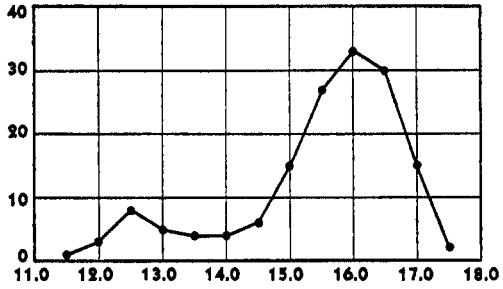

FIGURE 20. Frequency curve of the magnitude of the fifth star in open clusters of the Large Magellanic Cloud. Coördinates are numbers of clusters and photographic magnitudes.

each cluster rather than the first as an indicator of the maximum luminosity.

The frequency curve indicates in the first place the exceedingly high luminosity of the brightest stars in some of the open clusters, and in the second place the wide dispersion in luminosity. It may be that further information on the spectral classes will enable us to set up spectral criteria that will to some extent correlate with absolute luminosity; but for the present the curve serves chiefly to discredit earlier assumptions of the comparability of the brighter stars from one open cluster to the next.

d. Discovery and Distribution of Variable Stars. Probably the most interesting feature of the Magellanic Clouds

is the abundance of variable stars. In 1907 Miss Leavitt published the results of her examination of Bruce photographs, giving position coördinates and provisional magnitudes at maximum and minimum for 1777 variables. Dur-

FIGURE 21. Distribution of Miss Leavitt's variables in the Large Magellanic Cloud. Dots represent stars of magnitude 15.5 and brighter; circles, stars fainter than 15.5.

ing the current year a number of recent plates of the Large Cloud have been examined by the positive-on-negative method and at the time of writing nearly eight hundred new variables have been added to Miss Leavitt's list of 808. Positions and magnitudes are yet to be determined for the new discoveries; in the course of obtaining this information all

of the sixteen hundred variables will be remeasured, the frequency curve of median magnitudes will be determined as well as a frequency curve of the amplitudes of variation. Meanwhile we show in Figure 21 the distribution of the Leavitt variables throughout the Cloud.

The diagram on which the variables are plotted shows also the general structural features of the Large Magellanic Cloud. The diagonally elongated central part, outlined by dash and dots, is the main axis of the system; the full lines circumscribe the more conspicuously clustered regions; the broken lines indicate semi-clustered regions; and the remainder of the Cloud has been designated "open region." The density of stars varies extremely from the central axis to the open region. For instance, between the sixteenth and seventeenth photographic magnitudes there are approximately seventeen thousand stars per square degree in the "axis" region and only twenty two hundred stars per square degree in the "open" region, both of these numbers having been corrected for superposed stars of our galactic system.

The number of variables and the percentage of stars variable are shown in the following tabulation for the four different kinds of structure. Section I refers to the axis of the Cloud, section II to the heavily clustered parts, section III to the semi-clustered parts, and section IV to the open region.

It is of interest that the variable stars of the sixteenth magnitude and brighter are distinctly less frequent in the clustered regions than elsewhere. This phenomenon holds also in our Galaxy where variables in open clusters are practically non-existent. A recent study of 78 Harvard photographs by Mr. Miller, involving 15,500 stars in and near twelve open clusters, has revealed no certain case of stellar

DISTRIBUTION OF LEAVITT VARIABLES IN THE LARGE MAGELLANIC CLOUD

Photographic magnitude	I		II		III		IV		TOTAL	
	No. of vars.	No. per 100 stars	No. of vars.	No. per 100 stars	No. of vars.	No. per 100 stars	No. of vars.	No. per 100 stars	No. of vars.	No. per 100 stars
]14.1	3	0.9	7	0.1	8	0.4	13	0.8	31	0.4
14.1 —15.0	12	0.7	26	0.3	6	0.2	30	1.2	74	0.4
15.1 —15.5	54	2.9	66	0.9	33	1.0	64	1.9	217	1.4
15.6 —16.0	115	3.5	39	0.4	29	0.7	118	2.1	301	1.3
[16.0	58	0.1	19	0.5	13	0.1	88	0.1	178	0.1

variability. In globular clusters, on the other hand, variable stars are nearly always present, sometimes in great abundance.

e. New Periods for Magellanic Cloud Variables. Since periods have been published for less than five per cent of the variable stars discovered in the Magellanic Clouds, some doubt has arisen as to whether all the variables are periodic and adhere to the period-luminosity relation. The determination of all the periods and light curves must await the accumulation of a large number of photographs, the collection now on hand being insufficient to decide the periodicity and normality of all the variables measured. But recent accumulations of photographs on the Small Cloud have permitted a preliminary test of the generality of Cepheid variability. Miss Mohr and Miss Hoffleit have measured and studied all the known variable stars in a selected area of about one seventh of a square degree. Of the thirty three stars measured, two prove not to be variable at all; of the remaining thirty one variables satisfactory periods and light curves were determined for eighteen. The observations did not suffice to yield the periods for the other thirteen, the

measures being difficult for many stars because of the influence of adjacent images.

From this special survey we conclude that at least sixty per cent of the variables in the Cloud are typical Cepheids adhering to the period-luminosity relation, and we surmise that further observations will show that at least ninety per cent are normal.

As an exhibit of the general uniformity of stellar phenomena among the galaxies, the light curves of these eighteen Cepheid variables in the Small Cloud are illustrated in Figure 22. A comparison of the curves with those for Cepheids of similar period in our own galactic system shows as close an agreement in form as we find among the galactic Cepheids themselves.

Periods have been determined but not yet published for about fifty of the variable stars in the Large Cloud. The resulting period-luminosity relation is apparently identical with that found for the Small Cloud, but the dispersion about the mean curve is slightly larger. This dispersion may be due to the greater thickness of the Cloud, or to observational errors, or possibly to the effect of irregular obscuring nebulosities within the Large Cloud itself. It will be necessary, as soon as plates are available, to determine the period-luminosity relation separately for various parts of the Cloud. The magnitudes of the Cepheid variables may in themselves furnish data on the distribution in the Clouds of the dark nebulosities which otherwise cannot be detected.

The types of research now in progress, especially on the Large Magellanic Cloud, indicate that this nearby galaxy is a potential source of information that will help in the understanding of our own system. Future studies of the Magellanic Clouds will include: (1) an analysis of the globular clusters within the Clouds and a study of the vari-

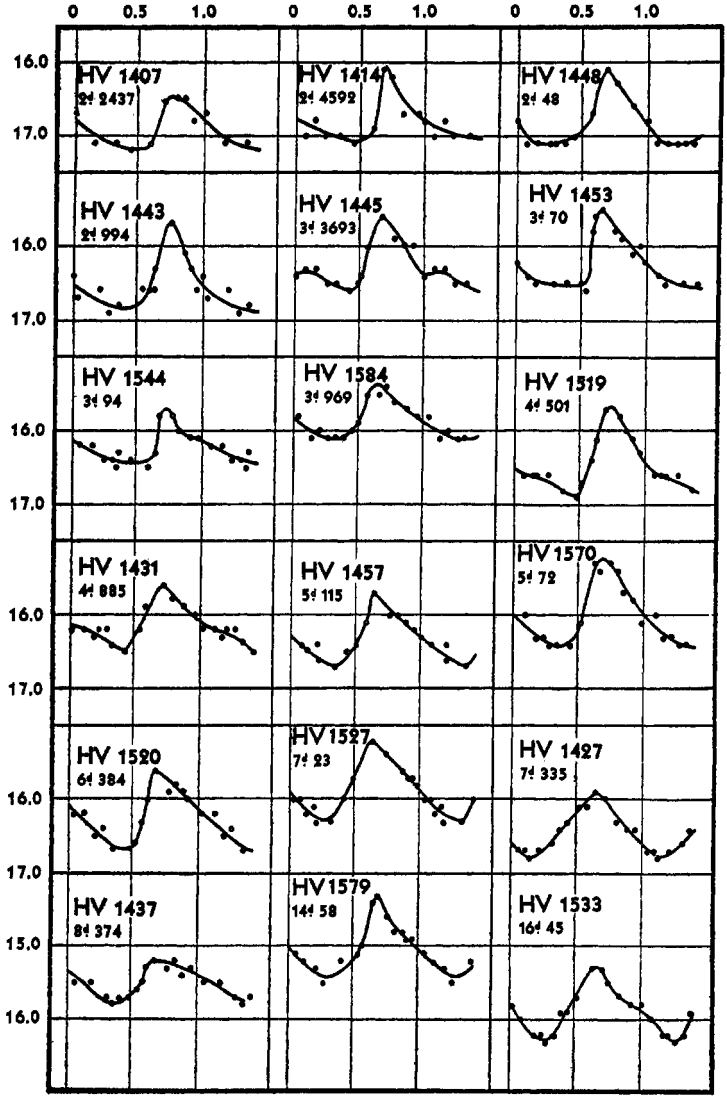

FIGURE 22. Light curves of variables in the Small Magellanic Cloud. Ordinates are photographic magnitudes; abscissae are fractions of the periods. Each point is the mean of five observations.

ables in the clusters; (2) the classification of the spectra of the highly luminous objects, especially in the open clusters; (3) further studies of the velocities in the line of sight, not only of the easily measured gaseous nebulae but also of the stars themselves, since the systematically high radial velocities will help in distinguishing the foreground stars, with their slow and random movements, from the members of the Clouds; (4) the extension of the study of the variable stars to those of the Cepheid type with periods less than one day. All of these researches should be carried forward rapidly with the aid of the 60-inch reflector.